Part 6: Metal Roofing From A (Aluminum) to Z (Zinc)

Attachment of Metal Panels

In this article, we look at panel attachment and how it provides the necessary wind resistance while still allowing panels to respond to thermal loads. We also look at "panel pinning"— where, why and how it is done.

Wind Effects and Standards

Metal panels that comprise the finished surface of a roof constitute an airfoil of sorts. As wind buffets the walls of the building, it is redirected up and over the roof. As this happens, negative pressure (suction) is created over certain zones of the roof surface, producing "lift" or "uplift". This is the same dynamic that makes airplanes fly and the effect can be quite exaggerated, threatening to tear the roof from its mounting. The frequency and strength of the metal panels' attachment, therefore, can be vital to roof survival during a windstorm.

Wind is measured by its speed in mph, but those units of measurement are not useful for designing

▲ An ASTM E 1592 test bed showing a 16-inch horizontal seam panel system pressurized to 126 psf using S-5 WindClamps™ at panel clip locations. The assembly failed at 220 psf. The failure pressure without seam reinforcement was 110 psf.
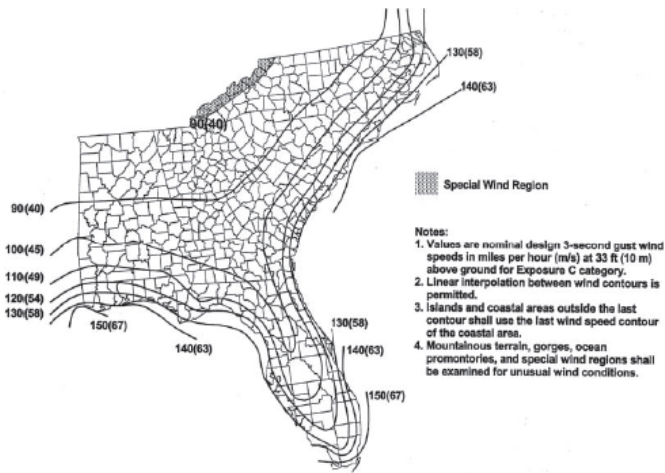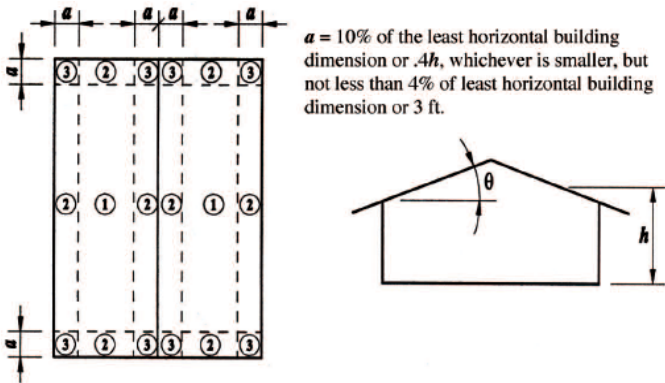
structures and roofs. The forces that are exerted on the roof surface are determined by taking the highest historical wind speed and translating it into pounds of positive or negative pressure per square foot of roof surface. The more concerning of the two is the negative pressure (uplift). The translation of wind speed into pounds of uplift force involves a number of tables, equations and a matrix of variables that include the height of the building and other size factors, as well as the "exposure factor" from the effects of the surrounding terrain or nearby buildings, all of which can increase or diminish wind pressures at the roof.

The metal roof assembly is a load chain in essence, with the weakest link representing the point of failure.

The National Weather Service maps maximum wind speeds from empirical data recorded over years of time for all areas of the country. Although the instrumentation (called an anemometer) measures wind speed at 33 feet above the ground, that speed is generally referenced as "ground wind speed." The ASCE-7.02 design standard is the most widely accepted engineering standard to take the recorded maximum ground wind speed in mph and determine the relative effects of the variables mentioned above to translate it into pounds per square foot (psf) on the roof surface. Note: As a result of increased hurricane severity over the last several decades, the mapping of recorded maximum wind speeds has changed.

130(58)
140(63)
90(40)

Special Wind Region

90(40)
100(45)
110(49)
120(54)
130(58)
150(67)
140(63)
130(58)
140(63)
150(67)

Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10 m) above ground for Exposure C category.
2. Linear interpolation between wind contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

▲ Design begins with the fastest 3-second gust as measured on the ground. "On the ground" means 33 feet above and lower. Because of ground friction, as building heights increase, wind speeds also increase; hence, a roof on a 100-foot-tall building will experience more severe wind effects than 1-story construction will. For related reasons, surrounding construction and topography also play a role, resulting in different "exposures."

The ASCE standard divides the roof into "zones", each of which will experience different uplift forces resulting from the same ground wind speed. Corner zones are where the wind effects are the greatest. Perimeters are next along with ridges on steeply sloped roofs.

The "field" (non-perimeter zone) of the roof is where wind uplift effects are the least. The dimensional size of each zone is determined by the building size and height. Once these design pressures are known, the ability of the panel system to resist them must be proven.

a = 10% of the least horizontal building dimension or $.4h$, whichever is smaller, but not less than 4% of least horizontal building dimension or 3 ft.

▲ Zones 1, 2 and 3 each have pressure coefficients that vary with other aspects of the structure. Zone 3 experiences the greatest pressures; Zone 1 the least. Zones near the ridge are nonexistent when the slope is below 7 degrees.

The resistance of panels and attachments to the uplift forces to which they will be exposed is calculated or tested. Most design parameters and specifications require testing rather than structural engineering calculation.

Wind Testing

Recognized test methods include Underwriters Laboratories UL 580, Factory Mutual 4471 and ASTM E1592. Most codes and standards recognize that these test methods are superseded by actual "wind tunnel" testing as the wind tunnel more accurately assimilates actual building geometries, wind speeds and the resulting wind effects on the roof. Why not simply require wind tunnel testing as a standard practice? The answer is cost. Wind tunnel studies are extremely expensive and each is specific to an individual building and roof geometry.

The named tests use various methods of inducing static pressure on the roof assemblies in an attempt to quantify their performance. Most of them are designed and intended for structural panels (panels installed over open support framing). In my opinion, they generally produce conservative results compared to the real-world effects of wind on a roof surface. This has to do with conservatism within the design standard and test methods, as well as the inability of any test to replicate the unusual "microbursts" that wind produces on a surface as opposed to prolonged sustained pressures.

Some testing at Mississippi State University™ using electromagnetic fields rather than air pressure get closer to the real effects of wind on structural metal panels; however, testing of this type is also too costly to be adopted as an industry-wide procedure. The effects of wind on a roof surface, which is installed over a deck, is known to be mitigated to some degree, but the industry tests noted here cannot reflect this and indeed some of them do not enable testing of these "non-structural" panels.

▲ Research funded by the Metal Building Manufacturers Association and American Iron and Steel Institute at Mississippi State University utilized electromagnetic fields to more accurately replicate the effects of wind on a roof surface. *Photo courtesy of the Metal Building Manufacturers Association.*

Because each test is very specific in terms of the material and assembly particulars, a manufacturer testing a new roof product may have to go through a battery of tests for each panel assembly that it wishes to market. This can mean dozens of tests costing thousands of dollars each. Such repetition is necessary, however, because there are many variables in actual assemblies. Those variables include the gauge and mechanical properties of the material, the geometric shape of the seam and profile, the dimensions of the seam, the strength of the clip or other attachment, the attachment frequency and the width of the panel. The metal roof assembly is a load chain, in essence, with the weakest link representing the point of failure.

Changing one of the variables means increasing or decreasing the strength of one of the links. But doubling the strength of one link does not necessarily double the strength of the chain—the failure point may just move to a different link. Frequently, the weakest link is that the panel seam unravels under pressure or lifts off the attachment clip. These

modes of failure can be strengthened by the use of external seam reinforcing, such as S-5 WindClamps™, at or between clip locations, often doubling the system's uplift resistance at very low costs.

▲ Solar installation mounted parallel to the angle of the roof can mitigate wind effects.
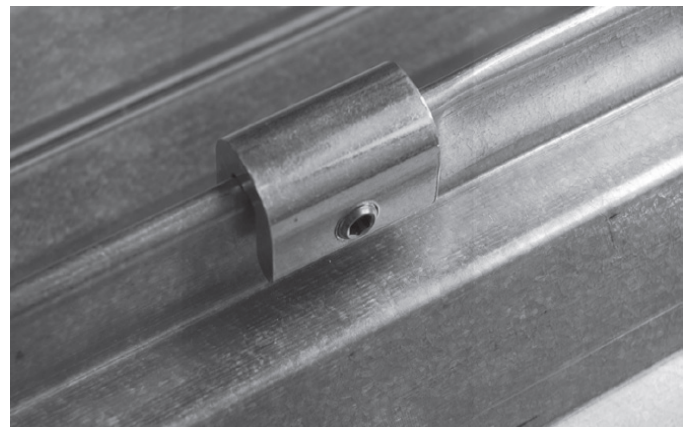
▲ S-5! WindClamp™ shown on seam.

It should be pointed out that roof-mounted ancillary items, like solar collectors that are a few inches above but planar to the roof, are not subject to the same wind pressures as the roof itself. In fact, they also have a mitigating effect on the pressures on the roof. Because the solar collector is a much smaller area than a roof, with air gaps at its edges that promote "leakage," a lesser amount of suction is exerted on its surface than on the plane of the

roof. Using the same design standards for such ancillaries will produce very conservative results indeed. Conversely, if the collector is mounted with some angle of tilt, the wind dynamic can be considerably more extreme.

Panel Attachment

Panels are attached with exposed or concealed fastenings. Exposed fasteners are used for certain panel types, including ribbed and corrugated profiles. This "direct" method of attachment can provide increased wind resistance but does not provide for thermal movement of panels and has the obvious disadvantage of penetrating the weathering surface.

Such methods and systems must be utilized with some precaution for these reasons. When the structure to which they are attached consists of wood or steel purlins, thermal cycling is relieved to some extent by flexure or rotation of the purlins.

▲ Through-fastened panels can provide greater wind resistance simply by increasing the fastening frequency, but this direct attachment does not provide very well for thermal response of the panels and adds holes to the weathering surface.

When the same systems are used over solid wood decks or bridged bar joists, however, fastening fatigue can result from repeated thermal cycling. It may, therefore, be a good idea to limit roof lengths for such applications because thermal movement is directly related to length.

Hundreds of years ago, brake-formed shapes were all fix-cleated to the structure, but their end-to-end joining was done with loose locks, and pan lengths were short, so thermal movement was never accumulated. Now, with roll forming manufacturing methods, panels have gotten considerably longer and thus accumulate more movement.

Most (not all) "concealed fastening" provides for differential thermal movement of panels to structure by the interface of the clip with the panel. A simple clip design would have this interface be a frictional engagement wherein the clip is rigidly attached to the building structure but slip-connected to the male seam component of the panel. This (one-piece) clip method is quite popular with most steep-slope roof products and especially those that have "snap-together" seam types. The clip is stationary but allows for differential movement between panel and clip.
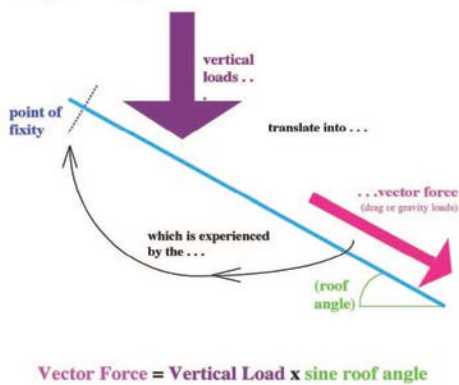

▲ Concealed fastened panels eliminate most fasteners from the weathering surface by using attachment clips inside the side-seam joint. The clips permit thermal movement, but because the "flat" of the panel is unrestrained, wind resistance is diminished. Under excessive load, the panel flat arcs upward, rotating the seam and disjointing.

When sealants are used within a panel seam, oftentimes the one-piece clip design cannot work. This is because the differential movement between

the panel and clip would abrade the sealant, jeopardizing weather integrity of the seam.

In such cases, a different clip design must be employed. The most popular designs for such a seam involve dual-component clips. The clip base is attached rigidly to the structure and the clip top folds into the panel seam. Differential movement then takes place within the clip itself, between its two components—base and top. It bears mentioning that the clip is an integral part of the assembly and unique in most cases to the panel profile with which it is used.

Calculating Drag Loads

Vector Force = Vertical Load x sine roof angle

SLOPE /12	DEGREES	SINE
1	4° 45'	0.08281
2	9° 28'	0.16447
3	15°	0.25882
4	18° 30'	0.3173
5	22° 30'	0.38268
6	26° 30'	0.4462
7	30° 15'	0.50377
8	33° 45'	0.55557
9	36° 45'	0.59832
10	39° 45'	0.63944
11	42° 30'	0.67559
12	45°	0.70711

Vertical
Roof Snow
= 35 #/S.F.

= 35psf x .382 x 60
= 800 plf x 1.33 ft

=1,069 pounds per panel

Roof

Sine = .382

5

12

60'

Panel is 16" wide (1.333 ft)

▲Drag loads should be calculated to verify adequacy of the panels' method and frequency of fixidity. In this example, the fixidity point should resist 1,069 pounds for each panel (plus safety factors).

Panel Fixity

Using clip fastenings that allow the panel to cycle freely in response to thermal loads also make it necessary to deliberately "pin" or "fix" the panel at some point along its length to prevent it from migrating out of its intended location. Gravity loads, or "drag loads" as they are sometimes called, will act in a direction parallel to the roof's surface trying to pull the panel down the slope of the roof. These loads are primarily comprised of vertical loads (snow, wind, foot traffic, etc.) on the roof's surface. The only resistance to these loads (other than the panels' designed point of fixity) is friction between panel and structure.
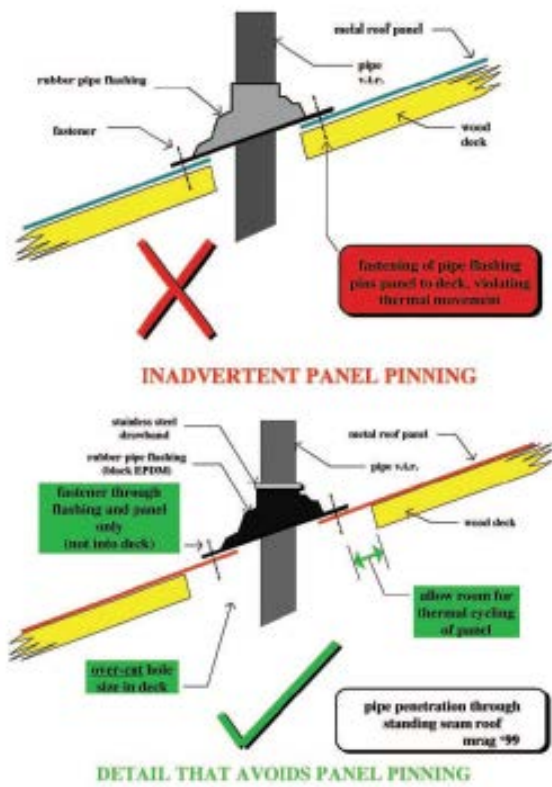
Panel fixity can be accomplished by using one or more "fixed clips," or by some method of direct panel fastening at the desired location. Use of the fixed clip method depends upon the nature of the interface of clip to panel seam; with some designs it is not possible.

The location of choice for fixity of steeply sloped architectural systems is most often at the ridge where direct (or through) fastenings can be hidden beneath a ridge cover. The system will then accumulate movement to its eave end.

Conversely, the popular point of fixity for low-slope systems is at the eave. The primary reason for this preference is that such systems are often hydrostatic by design, and it is much easier to waterproof a joint that is stationary than one that is moving. Exposed fastening is usually tolerable from an aesthetic standpoint on low-slope systems, so it is a logical choice. Such a system will then accumulate thermal movement to the ridge where a "bellows" style ridge flashing can accommodate differential movement of the two opposing roof planes while maintaining a hydrostatic seal.
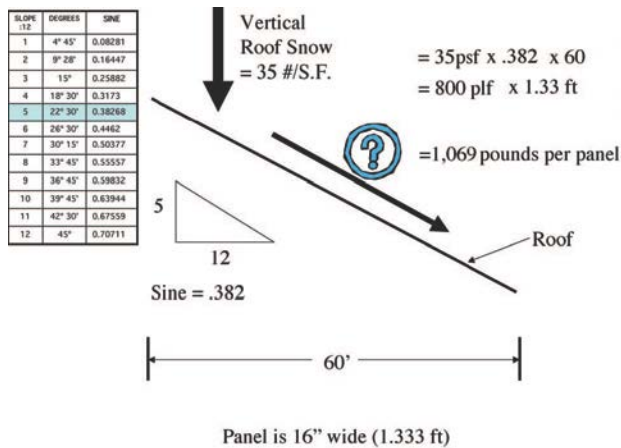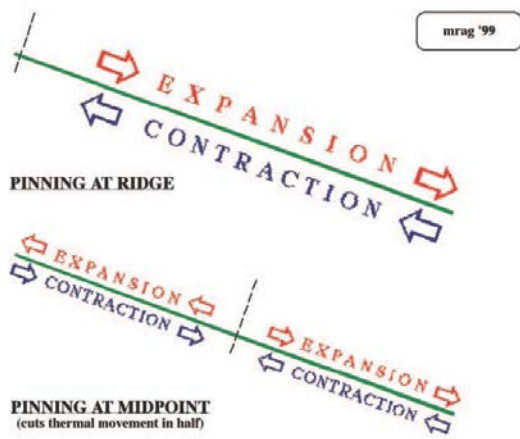
▲ The point of fixity may be at the ridge, eave or some midpoint. It is crucial that this point is singular and "dual pinning" does not occur.

▲ Often when a pipe is flashed through a steep roof product over a deck, it results in panel fixity. To avoid this, the deck should be overcut as shown.

These statements are not meant to be exclusive; there are exceptions in both cases. It is also occasioned in design to see a panel fixed at its midpoint, dividing thermal movement in half by sending it in both directions rather than one.

Having chosen a point of fixity for the metal panel system, it then becomes critical to ensure that such a point is singular. In other words, the panel should not be pinned inadvertently at any other point along its length. To do so would likely produce a failure from the thermal loads. On occasion, the thermal movement integrity of a roof system is violated because some construction detail or roof accessory mounting did not preserve this characteristic. Design and as-built construction should be scrutinized in this regard. A fascia break detail, for example, fixes the panel at the point of the break; to fix it again at its opposite end would constitute dual pinning. Other examples will be discussed in the next segment.
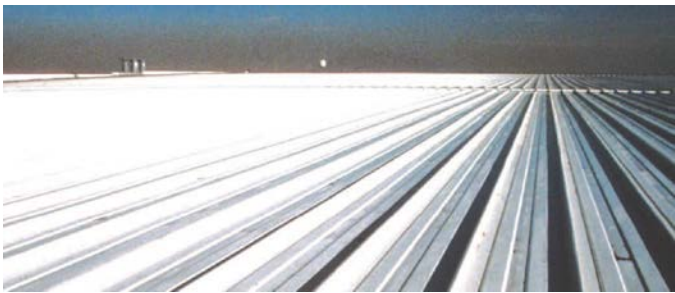
How Does Thermal Movement Occur?

As metal panels get hot, they expand, increasing their length dimension. When they get cold, they contract, reducing that dimension. This cyclical changing of dimension is called thermal movement. This is a linear effect. In other words, it will accumulate in direct proportion to the panels' "unbroken" length. If panels sections are joined end-to-end with mechanical fasteners through the lap, then the unbroken length is the total length of two or more panels, not just one.

Thermal movement does not accumulate across the width of the panels because the unbroken length in that axis is so small. The geometry of the panels and their joining method at side joints allows flexure at each joint so the thermal effects never accumulate. Small, unitized metal covering products, like shingles, in like fashion minimize unbroken length dimensions; hence thermal movement is rarely a consideration for such systems.
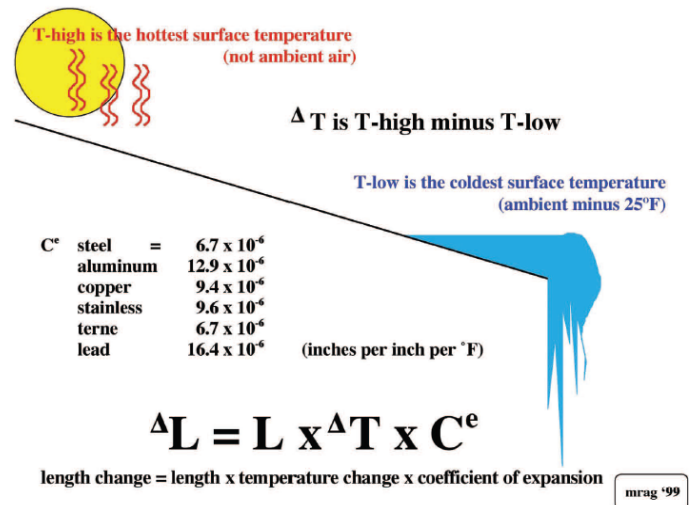
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A single metal panel exerts forces measured in tons when it tries to move thermally; hence, undue restriction of this anticipated movement easily can precipitate attachment fatigue and failure.

In cold winter nighttime scenarios, the low extremes of surface temperature can actually dip 25 or 30 degrees below ambient air. This is because of the principles of radiant energy. Skyward-facing objects radiate heat energy to the night sky. As this energy transfer occurs, the material loses BTU's (heat), reducing its temperature. It is this same effect that results in dew or frost on the ground, roof or windshield of your car when vertical surfaces do not experience dew or frost. It is a combination of these factors that can result in ΔT (difference of hottest to coldest surface temperatures) figures of close to 250 F in cold northern climates.


▲ In early days of metal roofing, pan lengths were short, so thermal movement never accumulated. As the "unbroken length" of panels increases, so does the dimensional gain or loss caused by surface temperatures.

Total (or worst-case) thermal movement is calculated by extending the material's coefficient of expansion over its length and the anticipated in-service temperature range throughout its service life. It is the surface temperature of the material and *not ambient air* that affects these extremes.

The maximum high-end temperature will be conditioned by the color of the panel and its solar absorption characteristics (lighter colors and high-gloss finishes will be cooler than dark colors and low-gloss finishes). A dark-colored panel with low gloss at right angles to the summer sun can approach temperatures of 200 F. Use of "cool" (or reflective) pigments can reduce these temperatures significantly because they lower the solar absorption.

T-high is the hottest surface temperature (not ambient air)

Δ T is T-high minus T-low

T-low is the coldest surface temperature (ambient minus 25°F)

C^e		
steel	=	6.7×10^{-6}
aluminum		12.9×10^{-6}
copper		9.4×10^{-6}
stainless		9.6×10^{-6}
terne		6.7×10^{-6}
lead		16.4×10^{-6}

(inches per inch per °F)

$$\Delta L = L \times \Delta T \times C^e$$

length change = length × temperature change × coefficient of expansion

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▲Different metals have different expansion coefficients. Note that aluminum will gain or lose about double the dimension of steel when subjected to the same temperature differences.

Strictly speaking, it is the differential expansion between roof panels and structure that must be accommodated by the panels' attachment clips. The clip (or its base in the case of two-piece clips) is mounted to the structure; panels move differentially to both. An open canopy structure may experience some temperature-induced change in dimension that
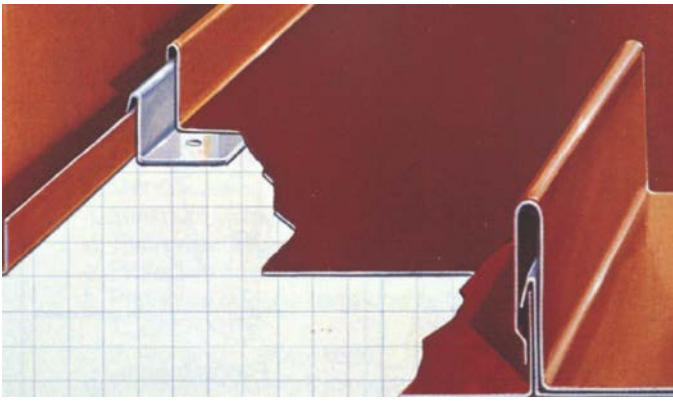
▲One-piece clip designs provide for thermal cycling by a sliding engagement of the panel seam. The differential movement takes place between panel and clip.
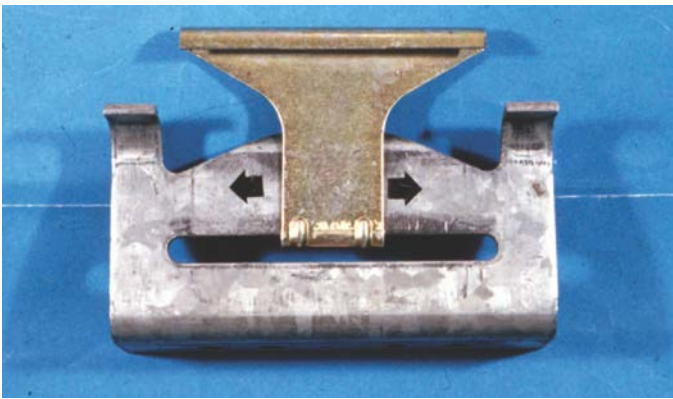
▲ Most two-piece clip designs provide for differential movement within the clip itself. The base is fixed to the structure and the top folds into the panel seam. The top does not move relative to the seam, preserving the integrity of seam sealants.

▲ If a panel is not "fixed" at some location, gravity, or "drag loads," can pull it down the slope of the roof.

would reduce the differential movement of its roof panels. Most often, however, the structure is a conditioned element inside a shaded or insulated building envelope. When this is the case, it experiences little or no change in temperature and therefore no change in length. This means the differential movement between roof and structure is equal to the total movement of the roof with no offsetting or mitigating thermal cycling of the structure.

Unlike many other aspects of engineering and design, calculations involving anticipated thermal movement are not augmented by factors of safety. In fact, it is not unusual to see as low as 80 percent of this theoretical calculated thermal movement actually used in design. Panels distort a bit; structural mountings or members may be deflected and strained, but roofs don't seem to fail.

On the other hand, if thermal-movement calculations are based upon ambient air (a frequent and novice mistake), they will often be only 50 percent of the correct extremes, and I have seen such roofs fail—repeatedly. A single metal panel exerts forces measured in tons when it tries to move thermally; hence, undue restriction of this anticipated movement easily can precipitate attachment fatigue and failure.

I have also seen professional engineers who try to prove the panel will undergo a "buckling" failure before the attachment will fail. In other words, it will hump up, oil-can or otherwise move out of plane to relieve the thermal forces. The trouble with this theory is that a member only buckles in compression (during an expansion cycle). Most attachment fatigue and failure occurs in tension (during cold-cycle contraction).

Manufactured two-piece clips usually include some mechanism to ensure they are centered at the time of installation. In theory, the roof panels are installed somewhere in the midrange of their in-service extremes. Although it may not be exactly at the halfway mark, common practice does not compensate for exact temperatures at installation. It

is absurd to suppose that installers will move clips to some predetermined location contingent upon installation temperature. Even if they did, the temperature is likely to be different when the mechanical seaming is done, thus botching the whole theory. Most clips find their own "centering" within the range of thermal cycling of the roof within the first few months of service.

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Certain references in this article to third-party publications, including standards, may be outdated. The reader should not rely on the accuracy of such references and should verify the applicability of this information with the local building and fire officials.

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